



Intensification of Microbial Desalination Cells (MDC) Efficiency using a Novel Microalgae-Integrated MDC Architecture



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INTRODUCTION

- Global freshwater availability is under stress due to climate change, population growth, and industrialisation [1]. Approximately four (4) billion people experience water scarcity at least once per month, prompting the rapid expansion of seawater desalination to augment freshwater supply [1].
- Conventional desalination technologies, particularly reverse osmosis (RO), are energy-intensive and contribute to greenhouse gas emissions, motivating the need for low-carbon alternatives [2].
- Microbial Desalination Cells (MDCs) have emerged as a promising technology capable of simultaneously desalinating seawater, generating bioelectricity, and treating wastewater [3]. However, widespread deployment has been hindered by low desalination efficiency and challenges in process scale-up [3].
- To overcome these challenges, we designed a novel microalgae-integrated MDC developed to enhance desalination performance through a combination of bioelectrochemical desalination and ion biosorption.
- Two salt-tolerant microalgae, *Chlorella vulgaris* (SAGNP-C-MDC) and *Synechococcus* sp. (SAGNP-S-MDC), were bioaugmented in the desalination chamber of MDCs to intensify the desalination efficiency.
- To develop a low-energy MDC system for sustainable water desalination for application in resource-limited settings.

METHODS

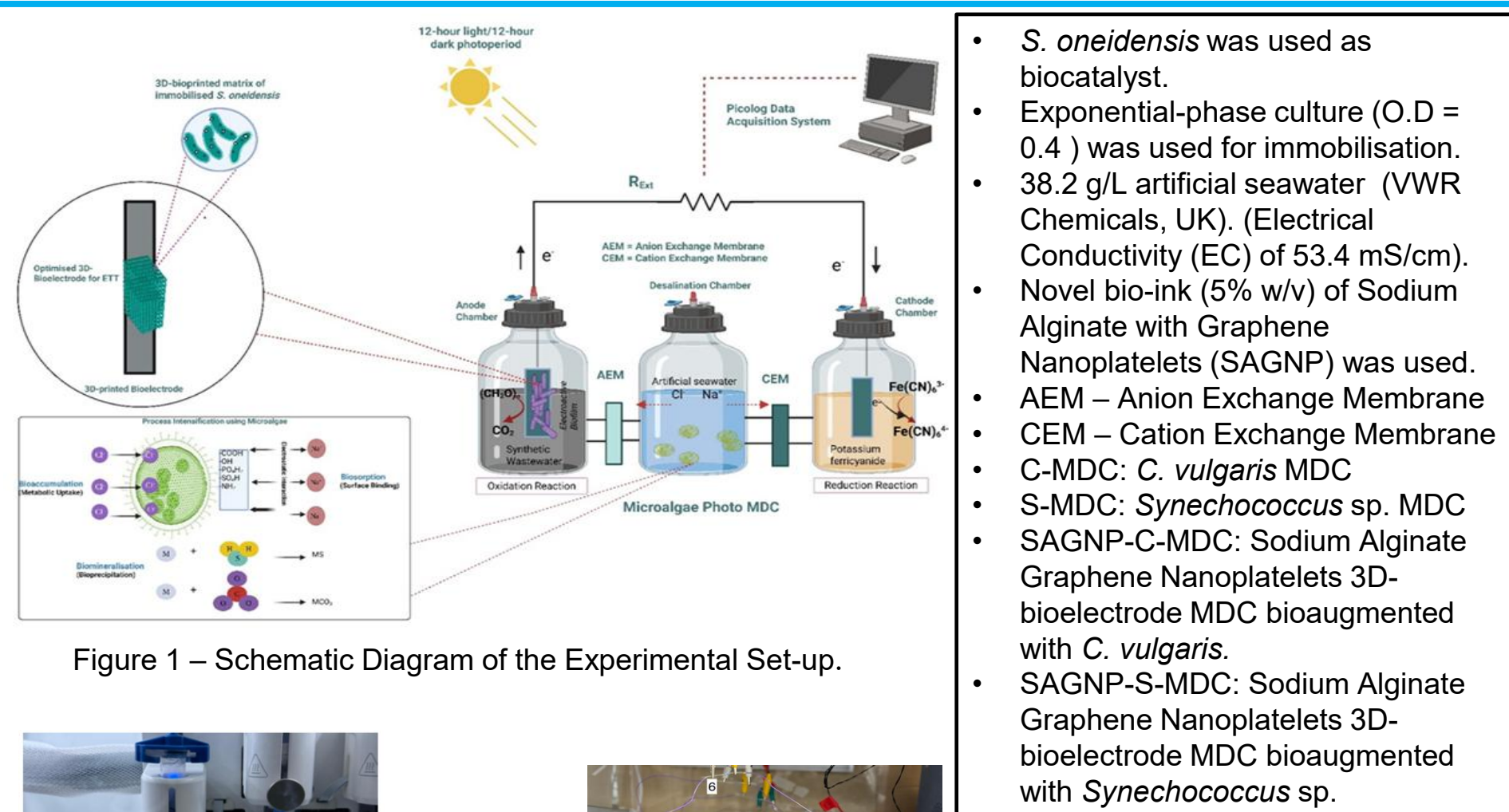


Figure 2 – 3D-bioprinting of *S. oneidensis* onto carbon electrode surface (bioelectrode) using 3D-bioprinter (XTM, Cellink, Sweden).



Figure 3 – The MDC Photo-bioreactor used in the experiment – 1. Anode chamber containing synthetic wastewater 2. Desalination chamber containing artificial seawater 3. Cathode chamber containing 1.0M $K_3[Fe(CN)_6]$ 4. AEM 5. CEM and 6. External resistor (20.5 kOhm resistor).

- S. oneidensis* was used as biocatalyst.
- Exponential-phase culture (O.D = 0.4) was used for immobilisation.
- 38.2 g/L artificial seawater (VWR Chemicals, UK). (Electrical Conductivity (EC) of 53.4 mS/cm).
- Novel bio-ink (5% w/v) of Sodium Alginate with Graphene Nanoplatelets (SAGNP) was used.
- AEM – Anion Exchange Membrane
- CEM – Cation Exchange Membrane
- C-MDC: *C. vulgaris* MDC
- S-MDC: *Synechococcus* sp. MDC
- SAGNP-C-MDC: Sodium Alginate Graphene Nanoplatelets 3D-bioelectrode MDC bioaugmented with *C. vulgaris*.
- SAGNP-S-MDC: Sodium Alginate Graphene Nanoplatelets 3D-bioelectrode MDC bioaugmented with *Synechococcus* sp.

RESULTS

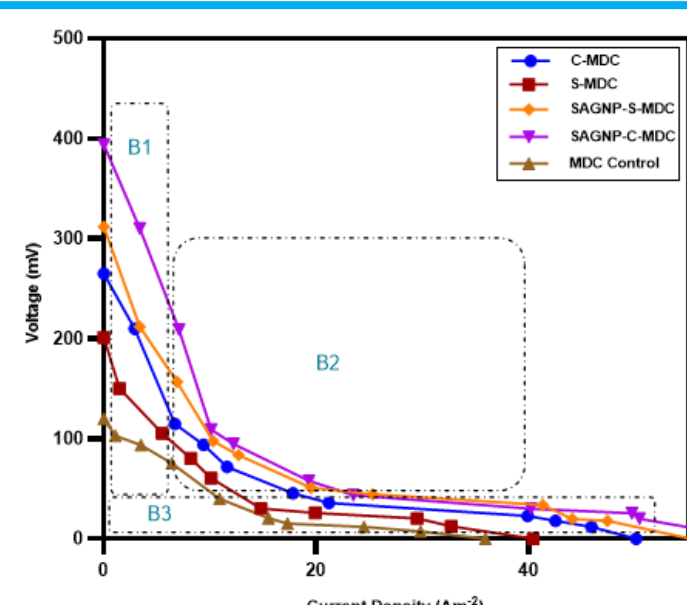


Figure 4 - Polarisation curves for the C-MDC, S-MDC, SAGNP-S-MDC, SAGNP-C-MDC and MDC control are plotted as voltage against the current density. The control MDC is the conventional MDC without microalgae or 3D-printed bioelectrodes.

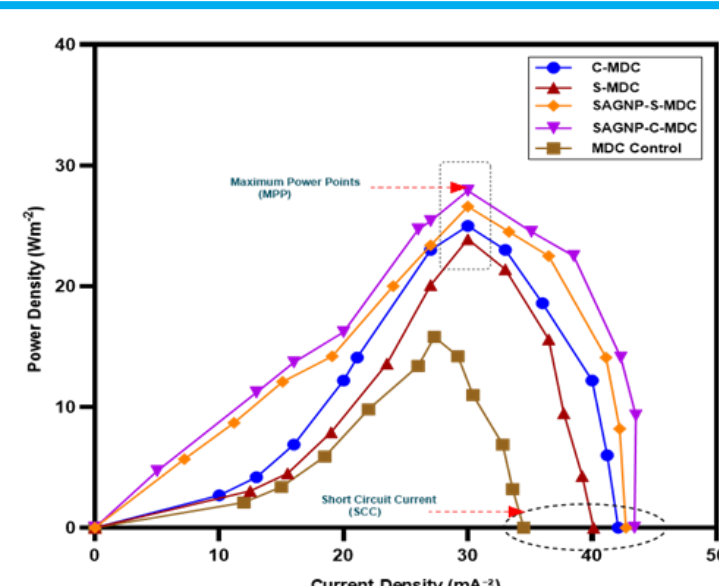


Figure 5 - Power density curves of the C-MDC, S-MDC, SAGNP-S-MDC, SAGNP-C-MDC, and the control MDC.

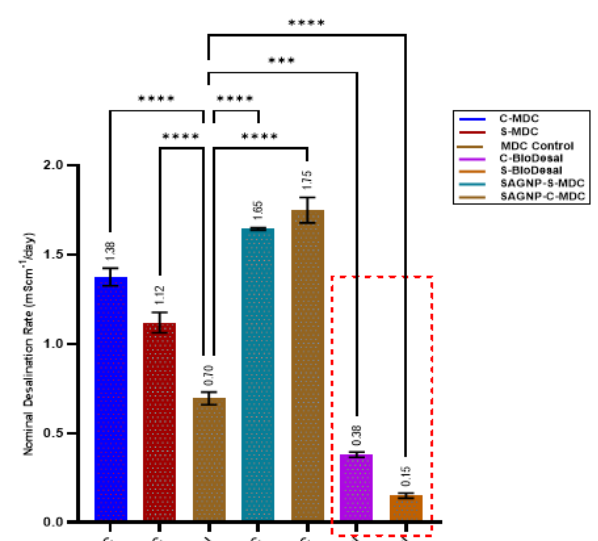


Figure 6 – Nominal desalination rate (NDR) of the C-MDC, S-MDC, SAGNP-S-MDC, SAGNP-C-MDC. Results are compared with the NDR of biodesalination using *C. vulgaris* and *Synechococcus* sp. (S-BioDesal and C-BioDesal), marked in red lines, and with the MDC control. One-way ANOVA was used to calculate statistical significance (Dunnett's Multiple Comparison Test adjusted p-values). ns = not significant ($P > 0.05$); * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P \leq 0.0001$.

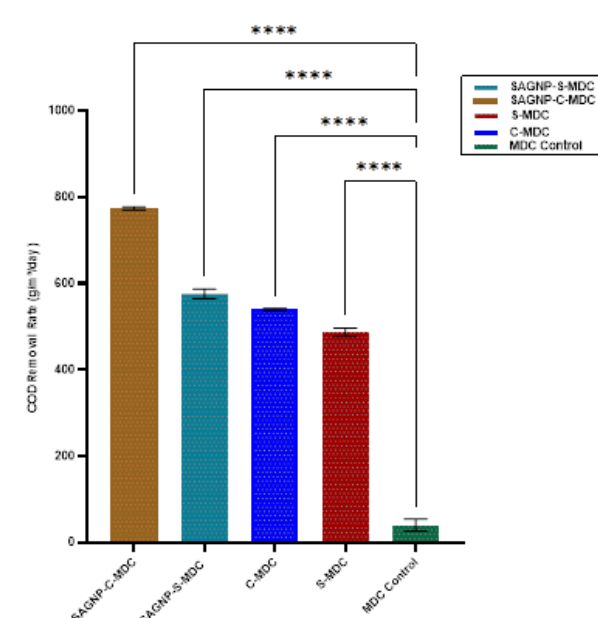


Figure 7 – COD removal rate of the MDC Configurations. One-way ANOVA was used to calculate statistical significance (Dunnett's Multiple Comparison Test adjusted p-values). ns = not significant ($P > 0.05$); * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P \leq 0.0001$.

DISCUSSION

- SAGNP-C-MDC achieved the highest peak OCV of 394 mV, which was 26.2% higher than that of SAGNP-S-MDC, which produced an OCV of 312 mV (Figure 4).
- The OCV recorded for the C-MDC was 265 mV, which was 31.84% higher than the S-MDC (201 mV) and 120 % higher than the MDC control (120 mV) (Figure 4).
- SAGNP-C-MDC achieved the highest power density with a maximum power point of 29.7 W/m² at a current density of 30 mA/A², which was about 24.3% higher than the SAGNP-S-MDC, which obtained a maximum power point of 23.9 W/m² at a current density of 30.5 mA/A² (Figure 5).
- SAGNP-C-MDC recorded the highest NDR of 1.75 mS/cm/h, which outperformed the other tested MDCs. Comparatively, the SAGNP-S-MDC achieved an NDR of 1.65 mS/cm/h, which was 38.2% higher than the S-MDC (1.12 mS/cm/h) and 17.8% higher than the C-MDC (1.38 mS/cm/h) (Figure 6).
- Comparing these results to the NDR obtained for the biodesalination experiment, *C. vulgaris* obtained an NDR of 0.38 mS/cm/h while *Synechococcus* sp. recorded 0.15 mS/cm/h, which indicates that *C. vulgaris* was suitable for biodesalination application.
- SAGNP-C-MDC obtained a COD removal rate of 761 g/m³/day corresponding to a removal efficiency of 92.5%. This was followed by SAGNP-S-MDC, which recorded 559 g/m³/day of COD removal (70%). Comparatively, C-MDC and S-MDC yielded 530 g/m³/day (64.5%) and 442 g/m³/day (57.7%), respectively.
- The findings suggest that integration of *C. vulgaris* into the desalination chamber could significantly improve the performance of MDCs, accounting for about 18.6% of the efficiency. This could be attributed to the ion biosorption capabilities of *C. vulgaris*, which occur concurrently with the bioelectrochemical desalination process within the MDC.
- The observed performance of the microalgae-integrated MDCs compared to the MDC control can be attributed to the ion uptake by the microalgae, resulting in a larger concentration difference (Donnan gradient) across the ion exchange membrane, which reduces overall internal resistance [4].

CONCLUSIONS

- The SAGNP-C-MDC outperformed the other tested MDCs, achieving an overall power density of 29.7 W/m² and a Coulombic efficiency of 28.9% ± 0.7%.
- The best overall MDC was the *C. vulgaris* coupled with the SAGNP-3D bioelectrode. The SAGNP-C-MDC achieved a desalination rate of 1.75 mS/cm/h (95.7%), comparatively higher than the SAGNP-S-MDC (1.65 mS/cm/h, 91.2%).
- This observed performance of *C. vulgaris* could be attributed to the abundant surface functional groups, such as amino, amide, carboxyl, and phosphate moieties, present on its cell wall, acting as active binding sites, facilitating ion uptake.
- The developed system provides robust proof of concept for high-efficiency MDC desalination and wastewater treatment. This approach aligns with the UN Sustainable Development Goal 6 (Clean Water and Sanitation).
- The MDC technology has shown potential for scalable, low-carbon desalination, contributing to circular bioeconomy strategies and sustainable water-energy nexus solutions.

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